

# Different Sagittal Angles and Moments of Lower Extremity Joints during Single-leg Jump Landing among Various Directions in Basketball and Volleyball Athletes

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**Abstract.** [Purpose] The purpose of this study was to assess the sagittal angles and moments of lower extremity joints during single-leg jump landing in various directions. [Subjects] Eighteen male athletes participated in the study. [Methods] Participants were asked to perform single-leg jump-landing tests in four directions. Angles and net joint moments of lower extremity joints in the sagittal plane were investigated during jump-landing tests from a 30-cm-high platform with a Vicon™ motion system. The data were analyzed with one-way repeated measures ANOVA. [Results] The results showed that knee joint flexion increased and hip joint flexion decreased at foot contact. In peak angle during landing, increasing ankle dorsiflexion and decreasing hip flexion were noted. In addition, an increase in ankle plantarflexor moment occurred. [Conclusion] Adjusting the dorsiflexion angle and plantarflexor moment during landing might be the dominant strategy of athletes responding to different directions of jump landing. Decreasing hip flexion during landing is associated with a stiff landing. Sport clinicians and athletes should focus on increasing knee and hip flexion angles, a soft landing technique, in diagonal and lateral directions to reduce risk of injury.

**Key words:** Jump landing, Joint angles, Joint moments

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## INTRODUCTION

Landing is a complicated task and has frequently been studied to determine athlete performance<sup>1)</sup> and injury risk of lower extremity<sup>2, 3)</sup>. Most knee injuries occur during one-foot landing leading to poor balance and subsequent injury<sup>4)</sup>.

Information about lower extremity biomechanics in landing will help to understand the characteristics of lower extremity injury and to develop programs for injury prevention. The magnitude of ground reaction forces (GRFs) during the landing phase has been associated with lower extremity injury<sup>5)</sup>. Biomechanical studies of landing have reported that GRFs are associated with jump height, footwear, landing surface, lower extremity flexion during landing<sup>6–9)</sup>, landing style<sup>10)</sup>, and vertical velocity of total body center of mass prior to contact the ground<sup>11)</sup>. Most studies have determined athlete performance and risk of lower extremity injury from high magnitude GRFs with adjustment of landing height<sup>1, 12)</sup>. However, GRFs are vector scale concerning in magnitude and direction. Athletes perform jump landing not just in one direction; they perform it in multiple

directions during games and practices. Poor postural stability was observed during diagonal and lateral landing compared with the forward direction<sup>13)</sup>. Conducting research with a forward jump-landing protocol might not completely understand the risk of lower extremity injury. Examining the difference in lower extremity angles and moments among different jump-landing directions could reveal previously overlooked information. Therefore, the purpose of this study was to investigate the effect of jump-landing directions on multi-joint control response of lower extremity in different directions.

Understanding multi-joint control of lower extremity during landing requires information concerning mechanical demand or moment, which is generated by muscles around the joint. Net joint moment (NJM) represents the resultant moment of the muscle actions between agonist and antagonist muscle groups, which can be estimated using the inverse dynamic technique<sup>1)</sup>. Peak lower extremity joint moments during landing increased with elevated landing height<sup>14)</sup>. No study has reported lower extremity moments during single-leg jump landing in various directions. In addition, angles of the ankle, knee, and hip joints in the sagittal plane were examined for comparison between directions of jump landing. Landing tasks are mainly performed in the sagittal plane. Therefore, the response to impact loading during landing depends on joint flexion of lower extrem-

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ity controlling by musculature<sup>15, 16</sup>). Less knee flexion angle at initial contact is the one factor influencing high reaction forces related to knee injury<sup>9</sup>). Moreover, landing with high ankle moment and less hip and knee flexion during landing is defined as stiff landing<sup>14</sup>). Therefore, the purpose of the current study was to investigate the effect of jump-landing direction on the sagittal angles and moments of lower extremity joints during single-leg jump landing in various directions. We hypothesized that the different jump-landing directions would exhibit different peak angles and moments of lower extremity joints during landing and also show a difference of lower extremity angles at initial contact.

## SUBJECTS AND METHODS

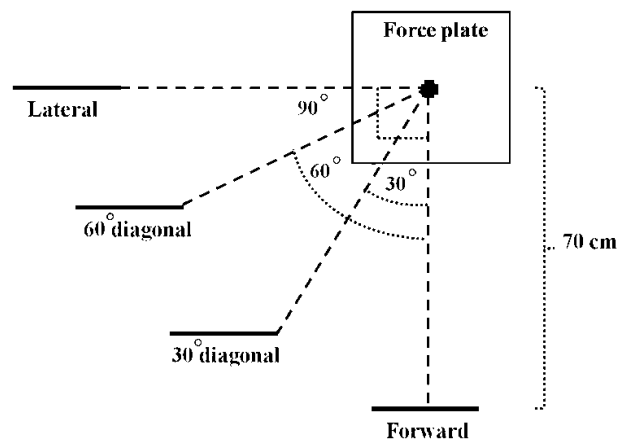
### Subjects

Eighteen male athletes (9 basketball and 9 volleyball athletes, mean age 20.2 years, range 19–24 years, mean body mass index 22.31 kg/m<sup>2</sup>, range 20.34–24.91 kg/m<sup>2</sup>) were included in the study. Basketball and volleyball athletes were selected because they frequently perform jumping and landing during games and practices. The subjects had been participating in an organized university team at least 3 times per week for at least 3 months prior to testing. All participants had no musculoskeletal disorders within 3 months prior to data collection. The exclusion criterion was a history of serious injury or operation of lower extremities (e.g., ACL injury, fracture, patellar dislocation). Only the dominant leg of the subjects was tested, which was identified based on the preferred leg when performing a single-leg hop for a distance<sup>17</sup>). Each subject read and signed an informed consent form, which was approved by the Committee on Human Rights Related to Human Experimentation of Mahidol University.

### Methods

Participants were asked to wear sport clothes and shoes. All tests were collected in the motion analysis laboratory at the Faculty of Physical Therapy, Mahidol University, equipped with a Vicon™ 612, Workstation 5.2 (Oxford Metrics, Oxford, UK). Kinematic data were captured by four video cameras at a frequency of 200 Hz. An AMTI force plate was used to measure GRFs at a frequency of 1,000 Hz. The sixteen reflective markers based on the Helen Hayes Marker Set<sup>18</sup>) were placed bilaterally on the subject's bony prominences, which consisted of the anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), thigh wand markers, lateral condyles of the femur, tibial wand markers, lateral malleolus, heels, and 2nd metatarsals.

Participants were allowed to practice jump landing 3 to 5 times in each direction in order to get accustomed the test. Participants were asked to perform the one-leg jump-landing tests from a 30-cm-high platform in four directions; forward (0°), diagonal at 30°, diagonal at 60°, and lateral (90°) directions (Fig. 1). The platform was placed 70 cm from the center of the force plate. The order of testing was selected randomly. The participants were instructed to stand with the dominant leg on a wooden platform and flex the left knee approximately 90 degrees with neutral hip position.



**Fig. 1.** Research setting of jump-landing directions

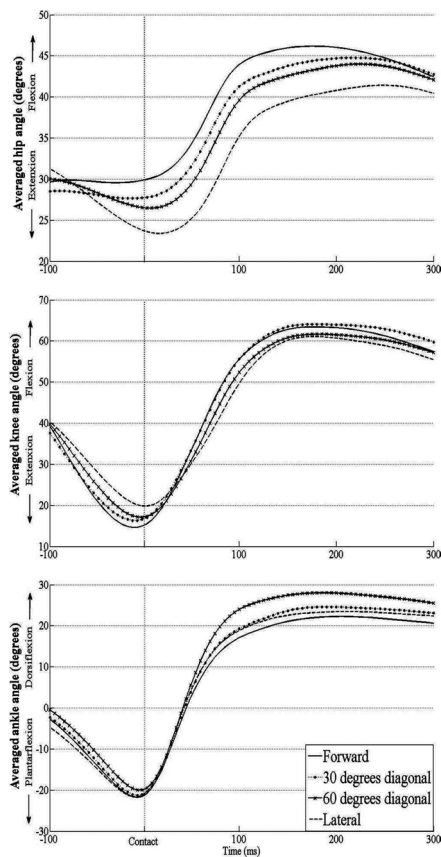
Subjects jumped from starting position in each direction and landed on the center of force platform.

Both hands were placed on the waist in order to eliminate variability in jumping mechanics due to arm swing. Each subject was instructed to carefully jump off the wooden platform without an upward jump action. They were instructed to jump and land while always facing and looking forward during jump-landing tests. If the subject was not able to maintain balance, land on the center of the force plate, maintain the hands on the waist, or moved off the force plate, the trial was considered unsuccessful. Unsuccessful trials were excluded and recollected. Three successful trials in each direction of jump landing were analyzed. Participants were allowed to rest five minutes between directions and to rest at least thirty seconds between trials.

Sixteen marker coordinates and GRFs were filtered by a fourth-order zero-lag Butterworth digital filter at cut-off frequencies of 8 Hz and 50 Hz, respectively. The cut-off frequencies were determined using the residual analysis technique<sup>19</sup>). The lower extremity model was constructed by the Plug-In Gait software. NJM in this study represented the internal moment. The peak angles and NJMs of lower extremity joints during the landing phase from three trials were averaged and analyzed. Moreover, the average angle of the lower extremity joints at foot contact was analyzed also. The statistical comparisons were performed with SPSS statistics 17. One-way repeated measures ANOVA was used to compare the main effect of direction. Pairwise comparisons were performed with Bonferroni correction. The level of statistical significance was set as a p-value less than 0.05.

## RESULTS

The patterns of angular displacement and net joint moment of the hip, knee, and ankle joints are shown in Figs. 2 and 3. The consistent patterns of lower extremity joint motions and moments were observed in ankle and knee joints. Motion and moment of the hip joint showed more variation than ankle and knee joints. Table 1 shows hip, knee, and ankle angles at initial contact. The peak angles of the hip, knee, and ankle during landing are also demonstrated in Table 1. Table 2 shows the peak internal moments of lower



**Fig. 2.** Averaged angular displacement of hip, knee, and ankle joints between 100 ms prior and 300 ms after foot contact in various directions of jump landing.

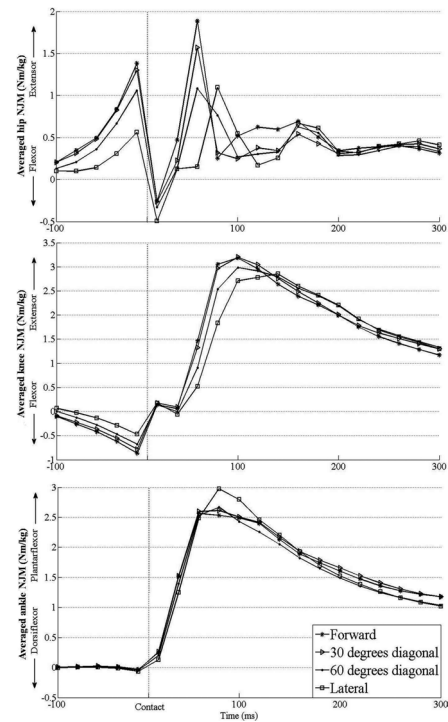
extremity joints during landing.

Table 1 shows that the main direction effect significantly influenced to the angles of the knee ( $F(1.554, 26.42)=11.832$ ,  $p=0.001$ ) and hip ( $F(3, 51)=23.91$ ,  $p<0.001$ ) joints at foot contact and to the peak angles of ankle ( $F(3, 51)=26.206$ ,  $p<0.001$ ) and hip ( $F(3, 51)=23.91$ ,  $p<0.001$ ) joints during landing.

There were significant differences in peak plantarflexor ( $F(3, 51)=5.632$ ,  $p=0.002$ ) and knee extensor ( $F(3, 51)=5.36$ ,  $p=0.003$ ) moments between directions (Table 2). A significantly higher peak plantarflexor moment in the lateral direction was observed compared with the forward direction in jump landing. Peak knee extensor moment in the lateral direction was significantly lower than in the other directions.

## DISCUSSION

Previous studies reported the effects of biomechanical parameters on lower extremities during jump-landing<sup>6-11</sup>. But the effect of jump-landing directions on lower extremity biomechanics has not been reported. Our findings showed that [1] knee and hip joints exhibited a trend for an increase and decrease in flexion angles at initial contact, respectively, [2] ankle and hip joints showed a trend for an



**Fig. 3.** Averaged internal moment of hip, knee, and ankle joints between 100 ms prior and 300 ms after foot contact in various directions of jump landing.

increase in dorsiflexion and decrease in flexion angles at peak during landing, respectively, and [3] an increase in mechanical demand of plantarflexor moment from forward to lateral direction of jump-landing was noted.

Our findings showed that the knee joint exhibited a trend for an increase in flexion angle at initial contact, while the flexion angle of the hip decreased. The hamstring muscle works to flex the knee, while the hip extends<sup>20</sup>. It seems that the hamstring muscle was used to control knee and hip joints in response to different directions of jump landing. Lateral jump landing increased knee flexion by  $4.3^\circ$  compared with the forward direction. Less knee flexion angle at initial contact is the one factor influencing high reaction forces related to knee injury<sup>9</sup>. When determining the knee angle at initial contact, lateral jump landing had less risk of lower extremity injury compared with other directions in the current study. The finding of this study demonstrated an increase in knee flexion angle from the forward,  $30^\circ$  diagonal,  $60^\circ$  diagonal, and lateral directions of jump landing, respectively. However, all athletes in the present study stated that lateral jump landing was the most difficult direction and might lead to injury. It might be that, in response to the change from the forward to lateral direction, athletes increased knee flexion at initial contact to control lower extremity flexion instead of combining ankle plantarflexion and hip flexion. The knee joint is the major part used to absorb shock during foot contact<sup>10, 21</sup>. Jump landing possibly needs more knee flexion for preparing the anticipated landing from forward,  $30^\circ$  diagonal,  $60^\circ$  diagonal and lateral

**Table 1.** Comparison of lower extremity angles at foot contact and at peak during the landing phase among various directions (mean (SD)). Positive values represent ankle dorsiflexion, knee flexion, and hip flexion angles. Negative values represent ankle plantarflexion, knee extension, and hip extension angles

Direction	Angle at foot contact (°)			Peak angle during landing phase (°)		
	Ankle	Knee	Hip	Ankle	Knee	Hip
Forward	-20.8 (5.4)	15.5 (4.2) <sup>ε β</sup>	30.0 (5.2) <sup>ε ε β</sup>	23.0 (5.1) <sup>ε β</sup>	65.2 (10.1)	47.8 (8.8) <sup>β</sup>
30°	-20.5 (4.2)	17.1 (4.0) <sup>β</sup>	27.8 (4.7) <sup>β</sup>	24.4 (4.4) <sup>β</sup>	66.0 (8.6)	46.3 (8.4)
60°	-20.3 (5.9)	17.3 (4.9) <sup>β</sup>	26.5 (4.7) <sup>β</sup>	25.7 (3.6) <sup>β</sup>	63.7 (7.7)	45.4 (8.4)
Lateral	-19.5 (6.6)	19.8 (6.0)	23.6 (4.8)	28.8 (4.1)	62.7 (8.6)	42.9 (8.9)

<sup>ε</sup> Statistically significant difference compared with 30° diagonal direction (p<0.05) <sup>ε</sup> Statistically significant difference compared with 60° diagonal direction (p<0.05) <sup>β</sup> Statistically significant difference compared with lateral direction (p<0.05)

**Table 2.** Comparison of peak internal moment of lower extremity joints during landing among various directions (mean (SD))

Direction	Net joint moment (Nm/kg)		
	Ankle plantarflexor	Knee extensor	Hip extensor
Forward	2.79 (0.56) <sup>β</sup>	3.39 (0.41) <sup>β</sup>	3.29 (0.82)
30°	2.84 (0.68)	3.43 (0.47) <sup>β</sup>	3.22 (0.96)
60°	2.90 (0.62)	3.33 (0.45) <sup>β</sup>	2.96 (0.69)
Lateral	3.13 (0.77)	3.12 (0.40)	3.14 (1.12)

<sup>β</sup> Statistically significant difference compared with lateral direction (p<0.05)

jump landing, respectively.

Regarding the peak angle of the lower extremity joints during landing, the results of the current study showed that peak ankle dorsiflexion increased as the jump-landing direction changed from forward to lateral, while the flexion angle of the hip joint decreased. Landing with an ankle-dominant strategy and less hip and knee flexion is defined as a stiff landing<sup>14</sup>. A stiff landing causes poor dissipation of energy, allows the noncontractile components (i.e., ligaments and cartilage) to absorb the landing energy, and could lead to an increased risk of lower extremity injury<sup>14</sup>. This study showed that the risk of lower extremity injury probably increased as the jump-landing direction changed from forward to lateral as a result of a decrease in peak hip flexion during landing. Increased flexion of knee and hip during single-leg landing can attenuate impact forces and enhance energy absorption in the sagittal plane<sup>22</sup>. Sport clinicians and athletes should be made aware and endeavor to increase the knee and hip flexion angles as a soft landing technique in the diagonal and lateral directions in order to reduce the risk of lower extremity injury.

This study showed that, before foot contact, the dominant NJMs of lower extremity joints exhibited in hip extensor, knee flexor, and ankle plantarflexor, that were controlled by feed forward neural system. After foot contact, only knee joint changed the dominant muscle group from flexor to be extensor dominance (Fig. 3). Peak moments of the lower extremity joints mostly occurred within 200 ms after foot contact while the body was moving downward. In order to prevent body collapse during landing, lower extremity muscles have to perform eccentric contraction

and create internal plantarflexor, knee extensor, and hip extensor moments to counter the body's downward motion. GRFs and lower extremity kinematics were used to calculate the NJM to gain insight regarding the selective method by which humans control lower extremity motion in multiple directions of jump landing. The results showed that there were significant differences in peak ankle and knee moments during landing. Moreover, the need in mechanical demand of knee extensor moment was less during landing in the lateral direction than in the other directions. Athletes preferred greater increases of peak plantarflexor moment as the jump-landing direction changed from forward to lateral. McNitt-Gray<sup>1</sup> reported that gymnastic and recreational athletes increased extensor moments of lower extremity joints as landing height increases. Larger increases in ankle and hip moments than knee moment may help to control balance during landing. The differences in the peak internal moments indicated the muscle function plays a different role to control lower extremity as the jump-landing direction changes. This means that the mechanical demand of the plantarflexor muscle group was greater as the jump-landing direction changed from forward to lateral.

Analysis of the lower extremity angles and moments during jump landing in the four directions showed that lower extremity biomechanics changed with different jump-landing directions. As they changed from the forward, 30° diagonal, 60° diagonal, and lateral directions, the athletes demonstrated an increase in knee flexion angle, while hip flexion decreased at initial contact. During landing, they showed an increased peak ankle dorsiflexion angle and plantarflexor moment and a decreased hip flexion angle.

Sport clinicians and athletes should focus on a soft landing technique, increased knee and hip flexion angles and extensor muscle eccentric control, particularly in the diagonal and lateral directions, to lower the risk of lower extremity injury.

In the current study, we could not determine the individual muscle function of each muscle group. Further study is needed to collect more information in order to deepen the understanding of lower extremity mechanics. Electromyography of lower extremity muscles will help to clarify how much muscle function in agonist and antagonist groups. However, the findings in the current study can only be generalized to basketball and volleyball athletes. The responses in terms of lower extremity angles and moments of a non-athlete group or athletes in other kinds of sports, such as soccer and gymnastics may be different. It would be interesting to assess the effect of jump-landing direction on the lower extremity biomechanics in other sport groups. Moreover, the other planes of lower extremity biomechanics during landing in multiple directions should be examined and would help to better understand the effect of jump-landing direction.

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